1879MNRAS..39..325N

On the practical Advantages of Hartnup's Method of testing Chronometers. By Arthur E. Nevins, Esq.

The difficulties attending the observation of lunar distances at sea and the errors to which the computation of Greenwich time therefrom is liable are well known to be so numerous that this method is hardly ever now practically used by officers in the merchant service, and therefore it becomes a very important matter to have all the reliable information which can be obtained about the performance of marine chronometers, as they are almost exclusively relied upon for ascertaining the longitude at sea.

Having had an experience in the management of chronometers at sea extending over several voyages, and having during that time found that the method of testing chronometers adopted by Mr. Hartnup at the Liverpool Observatory is exceedingly useful, both in selecting a chronometer for purchase and also in carrying on the time by it afterwards, I trust that some account of this experience may be useful to others.

Account of the performance of a Marine Chronometer from the time it left the maker's hands for a period of four years.

In 1874 I selected from the chronometers at Mr. Hartnup's Observatory the chronometer "George Timewell," 1656. This, like most new chronometers, was greatly gaining in its rate, my first three voyages exhibiting respectively $0^s.9$, $0^s.4$, and $0^s.2$ per day of acceleration.

After these voyages the instrument was tested in March, April, and May 1877, at the Liverpool, Observatory, preparatory to a voyage to Australia and India. The following Table shows the results obtained from this test:—

1877.	Mean Daily Rates. s	Mean Temperature Fahrenheit. °
March 10–17	−0·95	85
17–24	−0·05	70
24–31	−0·60	55
31–April 7	+0·65	70
April 7–14	−0·12	85
14–21	+0·33	70
21–28	−0·17	55
28–May 5	+0·78	70
May 5–12	+0·15	85
12–19	+0·80	70

The values of C and T we found to be—

$$C = -0^s\!\cdot\!0037 \qquad T = 70\cdot03.$$

1879MNRAS..39..325N

It will be seen from the Table of Observatory Rates given above that this watch was still gaining a little on its rate, and therefore R was assumed to be $+0^{s}\cdot80$, which was the rate kept during the last two weeks in which it was exposed to a temperature of 70° F., instead of $+0^{s}\cdot50$, which was its value as deduced from the whole test.

A table of rates for each degree of temperature from 40° to 90° F. was then calculated, the values of C and T being taken as obtained from the whole test by the above calculation, and the value of R being taken at $+0^{s}\cdot80$.

The formula used for these calculations is

$$\text{Rate in any given temperature} = R-(N^2 \times C),$$

where N is the difference of the temperature in question from T, reckoned in degrees Fahrenheit.

Throughout the voyage the rates were taken from this Table day by day according to the mean temperature of the previous twenty-four hours, and the results obtained during a fifteen months' voyage are given in the following Table:—

Date.	Errors of No. 1656 on G.M.T.		Differences.	Nature of Observations for Time.
	By Calculation.	By Observation.		
1877.	m s	m s	m s	
June 20	+1 29·0	+1 29·0	0 00·0	Left London.
Sept. 24	+2 10·5	+2 16·2	0 5·7	Melbourne time ball.
Nov. 15	+2 35·2	+3 8·1	0 32·9	Melbourne time ball.
1878.				
Feb. 11	+3 6·5	+3 56·0	0 49·5	Three stars with artificial horizon.
Feb. 25	+3 10·7	+3 54·5	0 43·8	Six stars with artificial horizon.
March 13	+3 14·9	+4 3·8	0 48·9	Six stars with artificial horizon.
July 3	+3 55·4	+4 53·0	0 57·6	St. Helena time ball.
Sept. 19	+4 50·7	+5 3·5	0 12·8	⊙ and ☽ with sea horizon off Start Point.

From this Table it will be seen that up to July 3, 1878, the rate had been subject to a continual acceleration in a gaining direction, but that, from that date to the end of the voyage, the watch had gone slower than its rate. By the daily comparisons which were made throughout the voyage with the two other watches on board, it was found that a sudden change in a losing direction in the rate of this watch took place on August 4; but what the cause of this change was I have not been able to ascertain.

As soon as possible after our arrival in England, this watch was sent to the Liverpool Observatory and submitted to a five weeks' test before being put into the maker's hands to be

1879MNRAS..39..325N

cleaned, and that test showed the values of C, T, and R to be as below:—

$$C = -0{\cdot}0034 \qquad T = 75{\cdot}42^{\circ}\,F \qquad R = +0{\cdot}73^{s}.$$

The maker said that when he took the watch to pieces he found that the oil had become deteriorated, but that otherwise he could not find anything to account for the change of rate which had apparently taken place.

The value of the temperature coefficients C and T remain constant for long periods.

On this occasion the maker (who is a thoroughly reliable man) was particularly requested to use every care to avoid in any way altering either the compensating weights on the balance or the timing screws, in order that the change produced by simply substituting oil in good condition for that which had become deteriorated might be ascertained from a comparison of the last test with its performance after being cleaned. As soon as it was cleaned it was again tested, and the result of a five weeks' test showed that the values of C, T, and R were as below:—

$$C = -0{\cdot}0037 \qquad T = 68{\cdot}7^{\circ}\,F \qquad R = -0{\cdot}88^{s}.$$

It will be seen from these figures that the value of C was, practically speaking, unaltered, that the change in the value of T was only slight, and that the watch went about $1^{s}{\cdot}6$ per day slower with the new oil, probably on account of its being a little fast in the short arcs, in which case it would go rather slower when the balance was vibrating through longer arcs after the watch had been cleaned.

The objection has been sometimes raised to Mr. Hartnup's method of correcting rates for change of temperature, that the values of C and T would need to be frequently redetermined. That such is not the case with a good watch when carefully cleaned and kept in repair, but that, on the contrary, the values of these two coefficients are nearly constant, will be seen from the following Table, showing the various values of C, T, and R which have been obtained for this watch from the tests to which it has been submitted at various times at the Liverpool Observatory:—

Date of Test.		C	T °	R s
August and September	1874	−0·0051	71·28 F	−0·08
April	1876	−0·0035	70·30	−1·63
March—April—May	1877	−0·0037	70·03	+0·50
October and November	1878	−0·0034	75·42	+0·73
November and December	1878	−0·0037	68·70	−0·88

1879MNRAS..39..325N

From these figures it will be seen that the value of T has, except in the case of the last two tests, been between 70° and 72° F., and that for the last four tests the value of C has remained almost constant, the abnormal value of C in the first test being probably caused by the rapid acceleration which was being then developed in the rate.

The values of R have been fluctuating, as might be expected in any watch which had been cleaned two or three times in the period under discussion.

On the performance of the Chronometers on board the ship "British Sceptre" during a fifteen months' voyage.

The last voyage on which this watch was used, and to which reference has been made above, was on board the ship "British Sceptre," commanded by Captain Henry Richards. On board this ship were two other chronometers, besides No. 1656 (which we will call for convenience S, standard), and by the kindness of Captain Richards I was enabled to have free access to them, and to all the papers connected with them. He also gave me the comparisons every day throughout the voyage of each of them with S, obtained by observing the simultaneous readings of all three of them. From these comparisons the first and second differences for each pair were obtained each day and tabulated. The mean temperature experienced was also recorded.

One of these chronometers, No. 196 (which we will call A), illustrated very well the advantages to be obtained from a knowledge of the temperature corrections for the rate of even a single watch in working with a set of two or more chronometers on a long voyage.

From the above mentioned comparisons it was found that in a temperature of from 55° to 60° F. the second differences from day to day between S and A were practically $0^{s}\cdot0$, showing that in that temperature the two watches were making the same rate; while in crossing the tropics, with temperatures ranging from 80° to 82° F., the difference of the rates of the same two watches was from $4^{s}\cdot5$ to $5^{s}\cdot0$ per day, A going slower than S by this amount.

All that was known about the going of A was that the chronometer maker, who had rated it in London in the months of May and June 1877, probably in a temperature of say 65° F., more or less, had given $-1^{s}\cdot3$ per day as the rate.

With regard to S the following Table of rates had been obtained in the manner which has been described above:—

Rates of S in various Temperatures.

The rate in	55°	60°	65°	70°	75°	80°	85°	Fahrenheit
was	−0·03	+0·43	+0·71	+0·80	+0·71	+0·43	−0·03	seconds per day.

1879MNRAS..39..325N

Under these circumstances it was a matter of certainty that the Greenwich Mean Time (and therefore of course the longitude) indicated by these watches would differ continually—as the temperature varied—and the following Table shows the amount of those differences, obtained on the passage from London to Melbourne:—

Table showing the relative performances of S and A, the rate of A not *being corrected for change of Temperature.*

Date	First Differences between S and A.						Differences of Greenwich Mean Times indicated.		Mean Temperatures Fahrenheit.
	By Calculation.			By direct Comparison.					
1877.	h	m	s	h	m	s	m	s	°
July 1	0	18	33·6	0	18	36·5	0	2·9	75
8	0	18	47·7	0	19	2·2	0	14·5	79
15	0	19	00·1	0	19	35·2	0	35·2	81
22	0	19	11·6	0	20	9·2	0	57·6	78
29	0	19	24·4	0	20	41·2	1	16·8	72
Aug. 5	0	19	38·7	0	21	4·6	1	25·9	59
12	0	19	50·0	0	21	7·5	1	17·5	58
19	0	20	1·0	0	21	7·9	1	6·9	59
26	0	20	12·4	0	21	9·1	0	56·7	61
Sept. 2	0	20	25·2	0	21	14·1	0	48·9	56
9	0	20	35·1	0	21	13·8	0	38·7	57
16	0	20	45·1	0	21	15·4	0	29·8	58
23	0	20	56·6	0	21	19·8	0	23·2	57
24	0	20	58·1	0	21	19·8	0	21·7	

The errors of these watches on September 24, by account, and also by the Melbourne time signal, were as below:—

	S.		A.
	m s		m s
Error by account	+2 10·6	Error by account	−18 47·5
,, observation	+2 16·2	,, observation	−19 3·6
Error of G.M.T.	0 5·6	Error of G.M.T.	0 16·1
Placing the ship to the West of the true Longitude	0° 1′ 24″	Placing the ship to the East of the true Longitude	0° 4′ 1″·5

1879MNRAS..39..325N

Method adopted to ascertain the rates of A in various temperatures.

From the information which has been already given, it will be seen that if the table of rates in various temperatures for S be assumed to be correct, all the data are at hand which are necessary for ascertaining the rates made by A in the various temperatures experienced between London and Melbourne.

The method adopted to find the rate of A in any temperature was as follows:—From the tabulated comparisons of these two watches the difference of the rates made by them was ascertained on every day on which that temperature was experienced as the mean temperature of 24 hours, from the column of second differences; the known rate of S was applied to this difference, and the result gave the rate of A in that temperature.

Thus it was found that on 7 days the mean temperature had been 56°, and on 5 days 80°, and the following calculations were made to ascertain the rates of A in temperatures 56° and 80° F.

Observed Second Differences between S and A.

	In temp. 56° s	In temp. 80° s	
	+0·3	−4·8	
	+0·4	−4·9	
	+0·0	−4·8	
	+0·1	−4·9	
	+0·1	−4·5	
	−0·4		
	−0·2		
Mean	+0·04	−4·78	Mean
Rate of S in temp. 56°	+0·07	+0·43	Rate of S in temp. 80°
∴ Rate of A in temp. 56°	+0·11	−4·35	∴ Rate of A in temp. 80°

In referring to these second differences,

+ denotes A gaining on S;
− „ A losing on S.

By a series of calculations similar to the above, the subjoined Table was obtained of the

Rates of A in various Temperatures.

Temperature Fahrenheit. °	Daily Rates of A. s	Temperature Fahrenheit. °	Daily Rates of A. s
53	+0·43	57	+0·03
54	+0·22	58	+0·21
55	+0·37	59	−0·08
56	+0·11	60	−0·06

1879MNRAS..39..325N

Temperature Fahrenheit.	Daily Rates of A.	Temperature Fahrenheit.	Daily Rates of A.
°	s	°	s
61	−0·26	74	−2·81
62	−0·20	75	−3·29
63	−0·01	76	−3·56
64	−0·43	77	−3·78
65	−0·79	78	−3·90
66	−1·06	79	−3·97
67	−1·48	80	−4·35
68	−1·61	81	−4·50
*		82	−5·03
73	−2·63	83	−5·43

From an inspection of this Table, it will be seen that the rates found in the way which has been described are not absolutely accurate; it is not to be expected that, where some certain degree of temperature has only occurred on one or two days, the rate for that temperature could be ascertained to a tenth or even half a second. Nevertheless the Table gives a very fair idea of the corrections to be applied. By using the last Table as a sort of general guide, the following Table of rates for A was drawn up for use at sea:—

In Temp.	55°	60°	65°	70°	75°	80°	85°	Fahrenheit
Rate of A =	+0·3	−0·3	−0·7	−1·9	−3·2	−4·3	−6·0	seconds per day.

Advantages obtained by correcting the rate of A for change of temperature.

The "British Sceptre" left Melbourne on November 15, 1877, bound to Madras, and on that day the errors of the two watches, S and A, were ascertained by observing the drop of the time ball, and during the passage the same rates were used for S as had been used on the previous passage, and the rates given in the last Table were used for A. From Madras we went to Coconada, and thence to Gobaulpore, at which port, on the night of February 24–25, 1878, a good set of observations for time were obtained. The relative performances of these two watches on the voyage from Melbourne to Gobaulpore is shown in the following Table:—

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* 69°, 70°, 71°, and 72° did not occur as the mean temperature for any 24 hours during the passage.

1879MNRAS..39..325N

Table showing the relative performances of S and A during 102 days, the rates of both being corrected for change of temperature.

Date.	Differences between S and A.						Differences of the G. M. Times indicated.		Mean Temperatures Fahrenheit.
	By Calculation.			By Comparison.					
1877.	h	m	s	h	m	s	m	s	°
Nov. 15	0	23	3·4	0	23	3·4	0	00·0	61
18	0	23	5·7	0	23	8·4	0	2·7	60
25	0	23	10·4	0	23	16·0	0	5·6	60
Dec. 2	0	23	16·0	0	23	23·0	0	7·0	66
9	0	23	28·3	0	23	36·7	0	8·4	77
16	0	23	58·1	0	24	7·6	0	9·5	82
23	0	24	35·0	0	24	43·5	0	8·5	84
30	0	25	15·2	0	25	23·6	0	8·4	82
1878.									
Jan. 6	0	25	52·8	0	26	1·4	0	8·6	83
13	0	26	31·5	0	26	37·4	0	5·9	82
20	0	27	7·9	0	27	11·4	0	3·5	81
27	0	27	41·9	0	27	46·0	0	4·1	80
Feb. 3	0	28	15·5	0	28	19·4	0	3·9	82
10	0	28	52·7	0	28	53·8	0	1·1	82
17	0	29	30·4	0	29	28·4	0	2·0	81
25	0	30	10·1	0	30	6·1	0	4·0	

On February 25, 1878, the ship being then at Gobaulpore, the time was obtained from the mean of six sets of observations of stars taken with a sextant and artificial horizon on shore, three of the stars being to the eastward and three to the westward of the meridian, with the following results:—

Errors on Greenwich Mean Time.

	Of S.				Of A.			
	h	m	s		h	m	s	
By account	+0	3	44·3		0	26	25·8	
By observation	+0	3	54·5		0	26	11·6	
Difference	0	0	10·2		0	0	14·2	
Error of longitude	0°	2′	33″	Westerly	0°	3′	33″	Westerly.

The rate for A given in London, as has been mentioned above, was $-1^{s}\cdot3$ per day, and that rate agreed very closely with the rate obtained in Melbourne by the time ball, and also with the mean rate made on the passage from London to Melbourne.

1879MNRAS..39..325N

It would therefore have appeared more than probable, if nothing had been ascertained about its rates by the comparisons with S, that $-1^{\rm s}\cdot 3$ was a correct sea rate for this watch; if that rate had been used from Melbourne to Gobaulpore, the result would have been as below:—

		h	m	s
Feb. 25.	Error of A on G.M.T. by account	−0	22	7·9
,,	,, ,, observation	−0	26	11·6
	(With rates *not* corrected for temperature) difference	0	4	3·7

i.e. error of longitude = $1^\circ\ 0'\ 55''\cdot 5$ easterly.

By applying the necessary temperature corrections to its rate, this watch indicated a longitude only $3\frac{1}{2}'$ *in error; but by using one mean rate in the usual manner, the error accumulated on the same passage would have been over a degree.*

Verification of the previously ascertained Tables of Rates for A.

The method has been already explained by which the rates made in various temperatures by A on the passage from London to Melbourne were ascertained from the second differences arising from the daily comparisons of the two watches under consideration. The same method was adopted in order to ascertain what rates A had made on the passage from Melbourne to Gobaulpore in the various temperatures experienced.

It will have been seen above that the G.M.T. deduced from S was in error to the extent of $10^{\rm s}\cdot 2$ on February 25, and as that error had been acquired in 102 days, the mean error of the rate would be $0^{\rm s}\cdot 1$, and therefore R would be $+0^{\rm s}\cdot 9$, instead of $+0^{\rm s}\cdot 8$. This correction was made to the rate of S before making the calculations from which the following Table was obtained of the

Rates of A *in various Temperatures.*

Temp. Fahr. °	Rates of A. s	Temp. Fahr. °	Rates of A. s
58	−0·83	72	−2·61
59	−1·30	74	−3·06
60	−0·34	76	−3·63
61	−0·58	78	−3·84
62	−0·54	79	−4·15
65	−0·89	80	−4·23
66	−1·19	81	−4·36
68	−1·71	82	−4·73
69	−1·70	83	−4·90
71	−2·00	84	−5·41

N.B. Temperatures 63°, 64°, 67°, 70°, 73°, 75°, and 77° were not experienced as the mean temperature for 24 hours during the period referred to by the above Table.

1879MNRAS..39..325N

The following Table shows the rates adopted for A on the passage from Bimlipatam (the port at which we completed our cargo) to London. It will be seen that it differs but slightly from the similar Table of rates for the same watch given above as used between Melbourne and Gobaulpore (p. 332).

In Temp.	55°	60°	65°	70°	75°	80°	85°	Fahr.
Rate of A	+0·3	−0·3	−0·8	−1·8	−3·2	−4·3	−5·8	secs. per day.

There is one remark which it is necessary to make about the last two Tables which have been given. The objection may be raised, that the rate given in the last Table for 55° temperature does not correspond with what it apparently ought to be from the rates given in the Table which precedes it for temperatures 58° and 59°. The reason for that is that these two temperatures were each only experienced for two days on the passage under discussion, and the two rates were therefore rejected in favour of the rates obtained on the passage from London to Melbourne, from much more numerous observations in the same two temperatures.

On March 12, 1878, the errors of the two watches on Greenwich Mean Time were obtained by observations of 6 stars (3 east and 3 west of the meridian) taken with a sextant and artificial horizon on shore at Bimlipatam. We left that port on March 19 for London, and on the passage the rates used for A were those given in the last Table. The rates used for S were based on the corrected value for R for that watch, which has been given above, namely $+0^{\rm s}\cdot 9$, instead of $+0^{\rm s}\cdot 8$ as used during the two preceding passages. They may be found from the Table of rates for that watch which has been already given (p. 328) by applying $+0^{\rm s}\cdot 1$ to each rate in that Table.

The next Table shows the results obtained from the two watches during the homeward passage.

Table showing the relative performances of S and A during a six months' passage, the rates of both being corrected for change of temperature.

Date.	Differences between S and A.						Differences of G. M. Time indicated.		Mean Temperatures Fahrenheit.
	By Calculation.			By Comparison.					
1878.	h	m	s	h	m	s	m	s	
March 12	0	31	27·4	0	31	27·4	0	00·0	
									83
17	0	31	55·0	0	31	54·6	0	00·4	
									84
24	0	32	35·5	0	32	34·4	0	1·1	
									86
31	0	33	18·2	0	33	14·9	0	3·3	
									87
April 7	0	34	2·6	0	33	57·7	0	4·9	
									86
14	0	34	45·6	0	34	37·6	0	8·0	
									84

1879MNRAS..39..325N

Date.		Differences between S and A.						Differences of G. M. Time indicated.		Mean Temperatures Fahrenheit.
		By Calculation.			By Comparison.					
1878.		h	m	s	h	m	s	h	s	
April	21	0	35	26·3	0	35	17·0	0	9·3	86
	28	0	36	9·3	0	35	59·7	0	9·6	83
May	5	0	36	47·8	0	36	38·8	0	9·0	78
	12	0	37	19·6	0	37	10·6	0	9·0	73
	19	0	37	44·5	0	37	35·2	0	9·3	75
	26	0	38	12·0	0	38	2·6	0	9·4	73
June	2	0	38	36·5	0	38	27·4	0	9·1	71
	9	0	38	57·7	0	38	47·3	0	10·4	66
	16	0	39	10·3	0	38	59·4	0	10·9	64
	23	0	39	20·3	0	39	8·4	0	11·9	64
	30	0	39	31·1	0	39	19·2	0	11·9	70
July	7	0	39	50·5	0	39	38·5	0	12·0	78
	14	0	40	21·6	0	40	7·0	0	14·6	80
	21	0	40	55·0	0	40	34·8	0	20·2	81
	28	0	41	30·4	0	41	10·2	0	20·2	82
Aug.	4	0	42	7·6	0	41	48·6	0	19·0	80
	11	0	42	42·0	0	42	20·5	0	21·5	83
	18	0	43	20·2	0	42	49·9	0	30·3	82
	25	0	43	57·1	0	43	19·0	0	38·1	74
Sept.	1	0	44	23·8	0	43	40·4	0	43·4	70
	8	0	44	43·6	0	44	4·9	0	38·7	68
	15	0	44	59·0	0	44	26·4	0	32·6	66
	19	0	45	6·2	0	44	36·7	0	29·5	

Advantageous results obtained by correcting the rates of A for change of temperature.

On July 3, 1878, the errors of the watches were obtained by the St. Helena time ball, as below :—

1879MNRAS..39..325N

Errors on G.M.T.

	Of S.			Of A.		
	h	m	s	h	m	s
By observation	+0	4	53·0	−0	34	34·0
By account	+0	4	55·5	−0	34	43·1
∴ Errors of G.M.T.	0	0	2·5	0	0	9·1
	Placing the ship to the Eastward of correct Longitude			Placing the ship to the Westward of correct Longitude		
	0°	0′	37″·5	0°	2′	16″·5

On September 19, 1878, the errors on Greenwich Mean Time of the chronometers were ascertained from observations of the Sun and Moon, taken with the sea horizon, Start Point being distant about 1½ mile, the Sun being to the east and the Moon to the west of the meridian; they were as follows:—

Errors on G.M.T.

	Of S.			Of A.		
	h	m	s	h	m	s
By observation	+0	5	3·5	−0	39	33·2
By account	+0	5	43·0	−0	39	23·2
∴ Errors of G.M.T.	0	0	39·5	0	0	10·0
	Placing the ship to the Eastward of correct Longitude			Placing the ship to the Eastward of correct Longitude		
	0°	9′	52″·5	0°	2′	30″

If the mean rate which has before been given for A, viz. $-1^{\mathrm{s}}\cdot3$ per day had been used on the voyage from Bimlipatam towards London, the error of the longitude on July 3 (at St. Helena) would have been 1° 10′ 51″, instead of 0° 2′ 16″·5, the error found after correcting the rates for change of temperature.

Again, by applying $-1^{\mathrm{s}}\cdot3$ as the daily rate for the rest of the passage up to September 19, the error of the longitude deduced from A would have been 2° 0′ 18″, instead of 0° 2′ 30″, its amount after correcting the rate for change of temperature.

With regard to the other watch, S, it seems unnecessary to make any further remarks.

I should only like to point out that the error of the longitude found from the mean of these two chronometers, when the rates of both had been corrected for change of temperature, would be 0° 6′ 11″·2 east (in time $0^{\mathrm{h}}\ 0^{\mathrm{m}}\ 24^{\mathrm{s}}\cdot7$), and, after a passage of over six months, this isvery near perfection.

1879MNRAS..39..337K

Conclusion.

In the *Monthly Notices*, vol. xxxv. (1874–75), Nos. 2 and 5, will be found two letters from me to Mr. Hartnup, giving the results obtained on a voyage from England to Calcutta and back, from two chronometers, for which the temperature corrections had been ascertained by Liverpool Observatory tests. When the results obtained on that voyage are combined with the facts which have been given in the present paper concerning the voyage in the "British Sceptre," it may be fairly said that my experience has shown, as far as it goes, that temperature corrections computed by Hartnup's formulæ are invaluable in carrying on time with chronometers at sea.

Notes on a Persian MS. of Ulugh Beigh's Catalogue of Stars belonging to the Royal Astronomical Society.

By E. B. Knobel, Esq.

The MS. which is the subject of the following notes, is a portion of a somewhat complete copy of Ulugh Beigh's Tables recently presented to the Royal Astronomical Society by Mr. Ranyard. This MS. is in Persian, and, from the date given on the last page of the Tables, it was written in the year 1255 Hegira = A.D 1839 for "Dr. James Bird."

The complete MS. is bound up in two parts. Vol. i. consists of Ulugh Beigh's "Introduction to the Catalogue and Knowledge of the Stars," and is very handsomely written and evidently by one hand throughout. Vol. ii. contains the "Samarcand Tables" and Catalogue of Stars, and shows evidence of having been written by two or three different hands.

Our knowledge of Ulugh Beigh's Catalogue of Stars is derived entirely from the translation made by Thomas Hyde and published in 1665; a second edition of this translation was published by Gregory Sharpe, in a complete collection of all Thomas Hyde's works, in 1767, and it is this copy which has been reproduced with notes by Mr. Baily in vol. xiii. of the *Memoirs of the Royal Astronomical Society.*

Hyde's translation was made from three Persian MSS., one in the Library of St. John's College, Oxford, another in the possession of Dr. Pocock, and the third in the Savilian Collection.*

A careful comparison of the Royal Astronomical Society's MS. with Hyde shows over one hundred and twenty differences in the longitudes and latitudes of stars.

A large proportion of these differences are due to errors of that particular kind which I have indicated in my notes to

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* The preface to the Catalogue which Hyde gives appears to be the thirteenth Treatise in the third part of Ulugh Beigh's Tables. *See* Sédillot, *Prolegomènes des Tables Astronomiques d'Oloug Beg*, 1853.